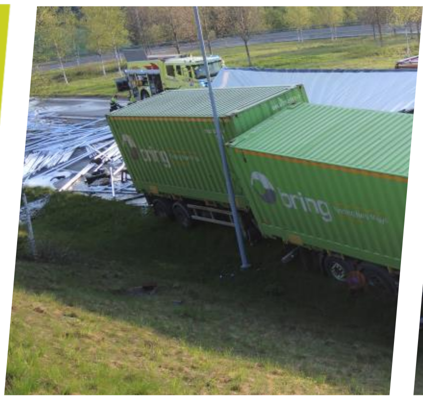
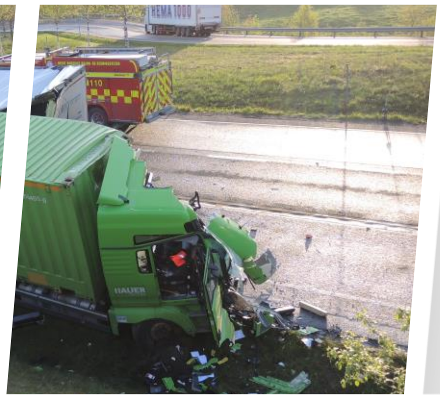
Norwegian Safety
Investigation Authority





Submitted May 2022

REPORT ROAD 2022/04

Head-on collision between two heavy goods vehicles on the RV 4 road just north of the Hagan tunnel near Slattum in Nittedal municipality on 27 May 2021

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The Norwegian Safety Investigation Authority (NSIA) has compiled this report for the sole purpose of improving road transport safety.

The purpose of the NSIA's investigations is to clarify the sequence of events and causal factors, elucidate matters deemed to be important to the prevention of accidents and serious incidents, and to make possible safety recommendations. It is not the NSIA's task to apportion blame or liability.

Use of this report for any other purpose than for road transport safety shall be avoided.

Photo: NSIA

This report has been translated into English and published by the NSIA to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

Table of contents

Report on head-on collision

Table 1: Data relating to the incident

Date and time:	Thursday 27 May 2021, at 03:15	
Scene of the accident:	Just north of the Hagan tunnel near Slattum in Nittedal municipality, Viken county (coordinates: UTM 33N 6659922 272403)	
Road system reference:	RV 4, S3D1, m3170	
Type of accident:	Head-on collision	
Type of transport:	Goods transport	
Vehicle type:	Vehicle A	Vehicle B
	Tractor unit and semi-trailer	Truck with drawbar trailer

Notification of the accident

At 03:33 on 27 Mai 2021, the NSIA was notified by the Traffic Control Centre Region East in Oslo of a head-on collision between two heavy goods vehicles on the RV 4 road just north of the Hagan tunnel in Nittedal Municipality. The NSIA decided to deploy personnel to the scene, because the accident appeared to be serious and involve casualties. The NSIA arrived at the scene at 04:00 and conducted investigations alongside the police's forensic experts and the Norwegian Public Road Administration's accident investigators.

Summary

On Thursday 27 May 2021, there was a head-on collision between two heavy goods vehicles on the RV 4 road just north of the Hagan tunnel in Nittedal municipality. The accident occurred in the early hours of the morning when there were few vehicles on the road. There was extensive damage to both vehicle fronts and to the left side of both driver's cabs, and the goods carried by the northbound vehicle broke loose and was scattered across the roadway. The driver of the southbound vehicle died, and the driver of the northbound vehicle was severely injured.

Vehicle A was northbound through the Hagan tunnel and started to make a left turn approximately 200 metres before the northern tunnel portal, where the final CCTV camera inside the tunnel is located. On leaving the northern portal, Vehicle A had moved all the way into the opposite lane.

Vehicle A continued its leftward turning movement up until about two seconds before the collision, possibly following an even curve from the location of the final CCTV camera in the tunnel to the point of collision. The speed of Vehicle A through the Hagan tunnel up until the point of collision developed in accordance with the longitudinal slope of the tunnel, the weight of the heavy goods vehicle and an even, passive application of the brakes.

The investigation has shown that the drivers could have spotted the headlights of each other's vehicles approximately five seconds before the collision, at the earliest, at which time they were on course to collide. The driver of Vehicle B did just about everything possible to prevent the collision and acted in line with what can be expected of a heavy goods vehicle driver in the given situation.

The investigation has shown that Vehicle A most probably entered the opposite lane because the driver fell asleep, at the same time as he kept the brake pedal and steering wheel in more or less stable positions up until the point of collision. Fatigue may have prevented the driver from becoming alerted when he crossed the centreline and rumble strip during the period before the accident.

Vehicle A's tractor unit was a Slovenian registered Volvo (2015 model), and had only limited safety devices and no technical driver support system. As from 7 July 2024, it will be mandatory for all vehicles in EEA Member States to have a Driver Drowsiness and Attention Warning (DDAW) system.

The present and previous investigations have shown that it is possible to fall asleep behind the wheel even if the requirements for working, driving and rest hours are complied with, and that drowsiness while driving is a safety problem. In submitting this report, the NSIA urges government agencies, transport companies and truck drivers to be aware of this safety problem. Both transport companies and customers ordering transport of goods by road should actively seek to use vehicles that are equipped with a DDAW system.

Based on the investigation, the NSIA submits a safety recommendation for the tripartite transport industry programme.

About the investigation

Purpose and method

The purpose of this investigation has been to determine what caused a heavy goods vehicle to veer into the opposite lane and collide head-on with another heavy goods vehicle heading in the opposite direction. The NSIA has also considered what can be done to improve safety and prevent the recurrence of similar accidents and fatal consequences in the future.

The accident and the circumstances surrounding it have been investigated and analysed in line with the NSIA's framework and analysis process for systematic safety investigations (the NSIA method[1]).

Sources of information

- The Norwegian Public Roads Administration (NPRA): expert report, tachograph data and CCTV video recordings
- The Police: information from the investigation of the accident
- Interviews with parties involved
- Dobravc transport d.o.o.: information about the driver of Vehicle A and the heavy goods vehicle he was driving
- Volvo Norge AS: information about Vehicle A's tractor unit
- The Norwegian Truck Owners Association: information about load securing

The investigation report

The first part of the report, 'Factual information', contains a description of the sequence of events, related data and information gathered in connection with the accident, and describes the NSIA's investigations/examinations and related findings.

The second part, the 'Analysis' part, contains the NSIA's assessment of the sequence of events and contributing causes based on factual information and completed investigations/examinations. Circumstances and factors found to be of little relevance to explaining and understanding the accident are not discussed in any depth.

The final part of the report contains the NSIA's conclusions and safety recommendations.

[1] *NSIA – Norwegian Safety Investigation Authority. See https://havarikommisjonen.no/About-us/Methodology*

1. Factual information

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1.1 Sequence of events

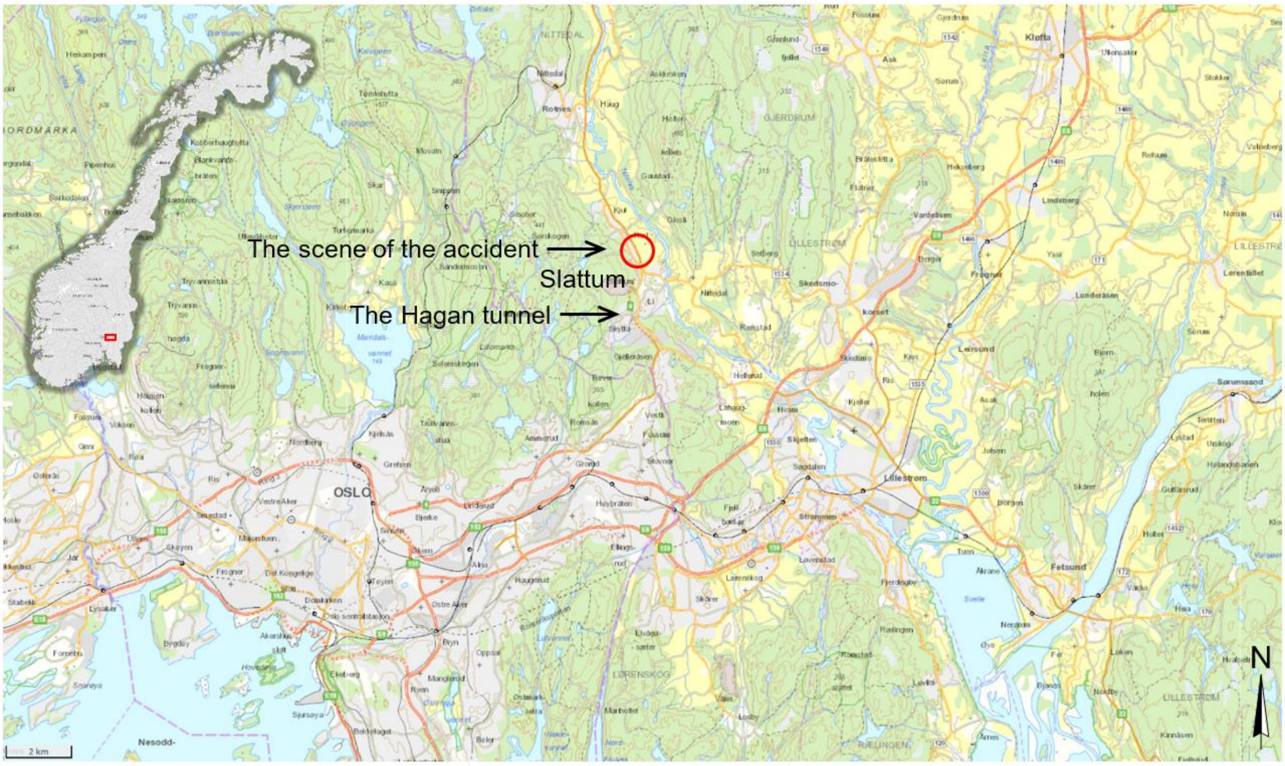

Figure 1: The accident occurred on the RV 4 road just north of the Hagan tunnel near Slattum in Nittedal municipality. The scene of the accident is marked with a red circle. Map: © Norwegian Mapping Authority. Illustration: NSIA

A heavy goods vehicle (Vehicle A) carrying aluminium sections was northbound on the RV 4 road towards Raufoss, when it collided with a southbound heavy goods vehicle (Vehicle B) at 03:15 in the early hours of 27 May 2021 (see Figure 1 and Figure 2). Driving through the tunnel, in a speed of up to about 106 km/h, Vehicle A had not encountered any traffic in the opposite direction before that time. Inside the tunnel, Vehicle A kept to its own lane up until it was approximately 200 metres south of the northern tunnel portal. On leaving the tunnel, the vehicle had moved all the way into the opposite lane at a speed of about 78 km/h. At the same time, Vehicle B was approaching the Hagan tunnel from the north on the same road at a speed of about 85 km/h. The driver of Vehicle B barely managed to hit the brakes, but a collision was unavoidable. The collision occurred approximately 120 metres north of the northern tunnel portal.

Parts of the fronts of both driver's cabs took the impact when the vehicles crashed into each other in the southbound lane at a speed of respectively around 78 km/h and 55 km/h. The cargo on Vehicle A was hurled out of the semi-trailer and the cab tipped down onto the roadway when the vehicle stopped. Both drivers suffered crush injuries and were trapped after the collision. The driver of Vehicle A survived, while the driver of Vehicle B died at the scene of the accident shortly afterwards.

Figure 2: Approximate point of collision (marked in red) and the direction in which the vehicles involved were moving. Photo: © Norwegian Mapping Authority. Illustration: NSIA

1.2 Survival aspects

The notification and rescue work was timely and as could be expected under the circumstances.

The buckles on the drivers' seat belts were stuck in the locked position after the accident. Furthermore, both seatbelts were cut when the vehicles were examined at the scene of the accident after the rescue effort. The NPRA's (2021) examinations of the seat belts after the accident indicated that they had been worn. There was survival space[2] in both driver's cabs after the accident (see Figure 3 and Figure 4).

1.3 Personal injuries

Table 2: Personal injuries

Injuries	Driver	Passengers	Others
Fatalities	1		
Serious	1		
Minor/none			

Both drivers suffered serious crush injuries and were trapped after the collision. The driver of Vehicle B died shortly afterwards. The driver of Vehicle A was cut loose and transferred to Oslo University Hospital at Ullevål, and he survived the accident.

[2] *The remaining space available to the driver and any passengers inside a car for the purpose of survival after deformation or indentation of the vehicle body in a collision.*

1.4 Vehicle damage

1.4.1 DAMAGE TO VEHICLE A

Vehicle A was extensively damaged on the left side of the cab front and the left side of the trailer front, as a consequence of the collision. Figure 3 also shows how the cab of Vehicle A tipped forward after the collision.

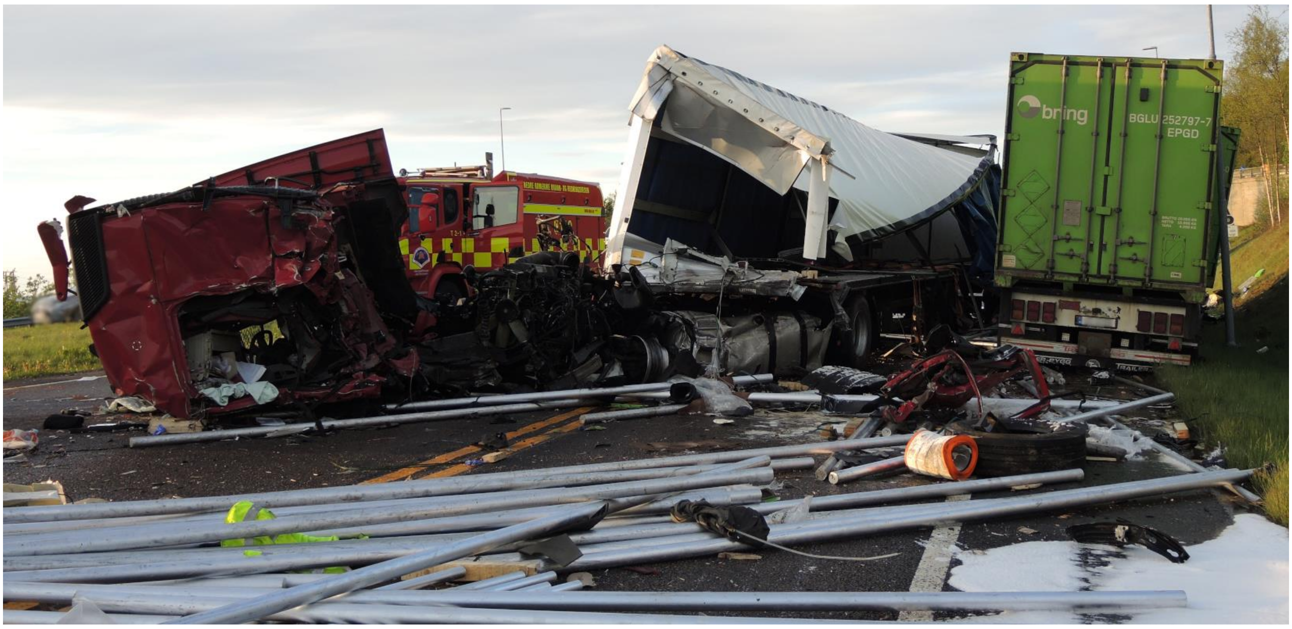

Figure 3: Vehicle A with the red driver's cab to the left in the photo, as it appeared approximately 1.5 hours after the accident. Photo: NSIA

1.4.2 DAMAGE TO VEHICLE B

Vehicle B sustained extensive damage to the front and left side of the cab, as a consequence of the collision (see Figure 4). In addition, the foremost cargo container was buckled inwards both at the front and at the back.

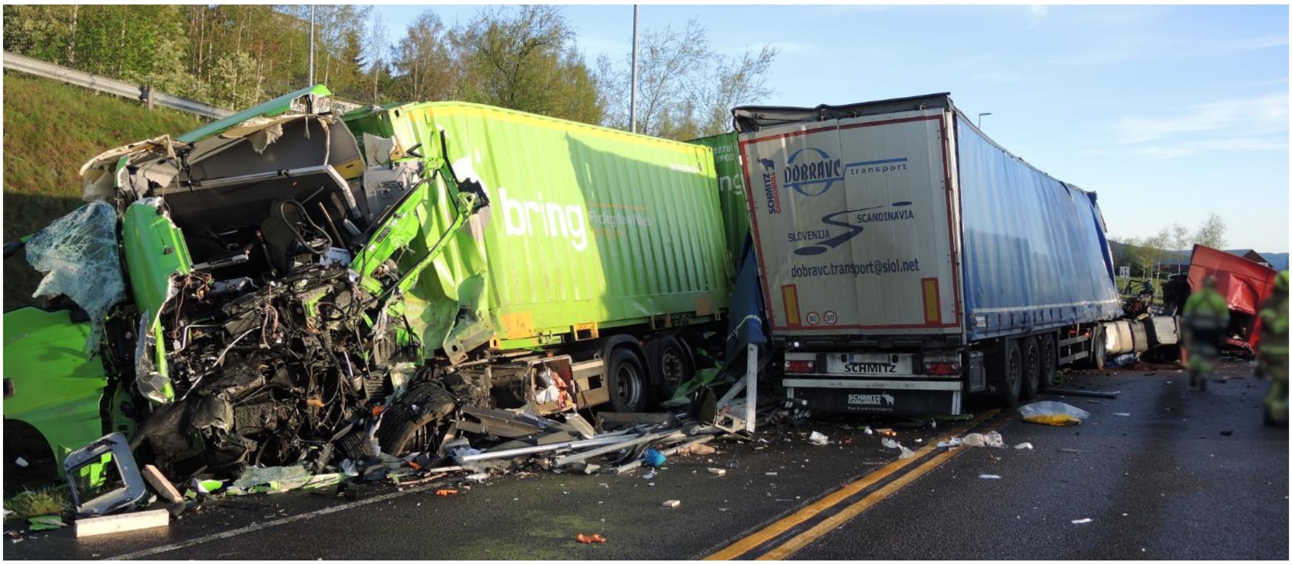

Figure 4: Vehicle B to the left in the photo, as it appeared approximately 1.5 hours after the collision. The photo was taken after the rescue work. Photo: NSIA

1.5 Scene of the accident

The collision occurred approximately 120 metres north of the northern tunnel portal on the RV 4 road. The collision occurred against one end of a curve, where the road had two lanes and a deceleration lane (exit ramp) along the northbound lane. The speed limit at the point of collision was 70 km/h. The road had solid edge markings, a double and reinforced centreline (with a milled-in rumble strip) and a dividing line marking the deceleration lane.

Figure 5 shows how Vehicle A's cargo was hurled out of the semi-trailer, both to the left and forward of the cab in the direction it was travelling. Vehicle A's cab tipped forward in the collision and tilted to the right in relation to the run of the roadway, ending up with the front window resting on the ground (see Figure 3).

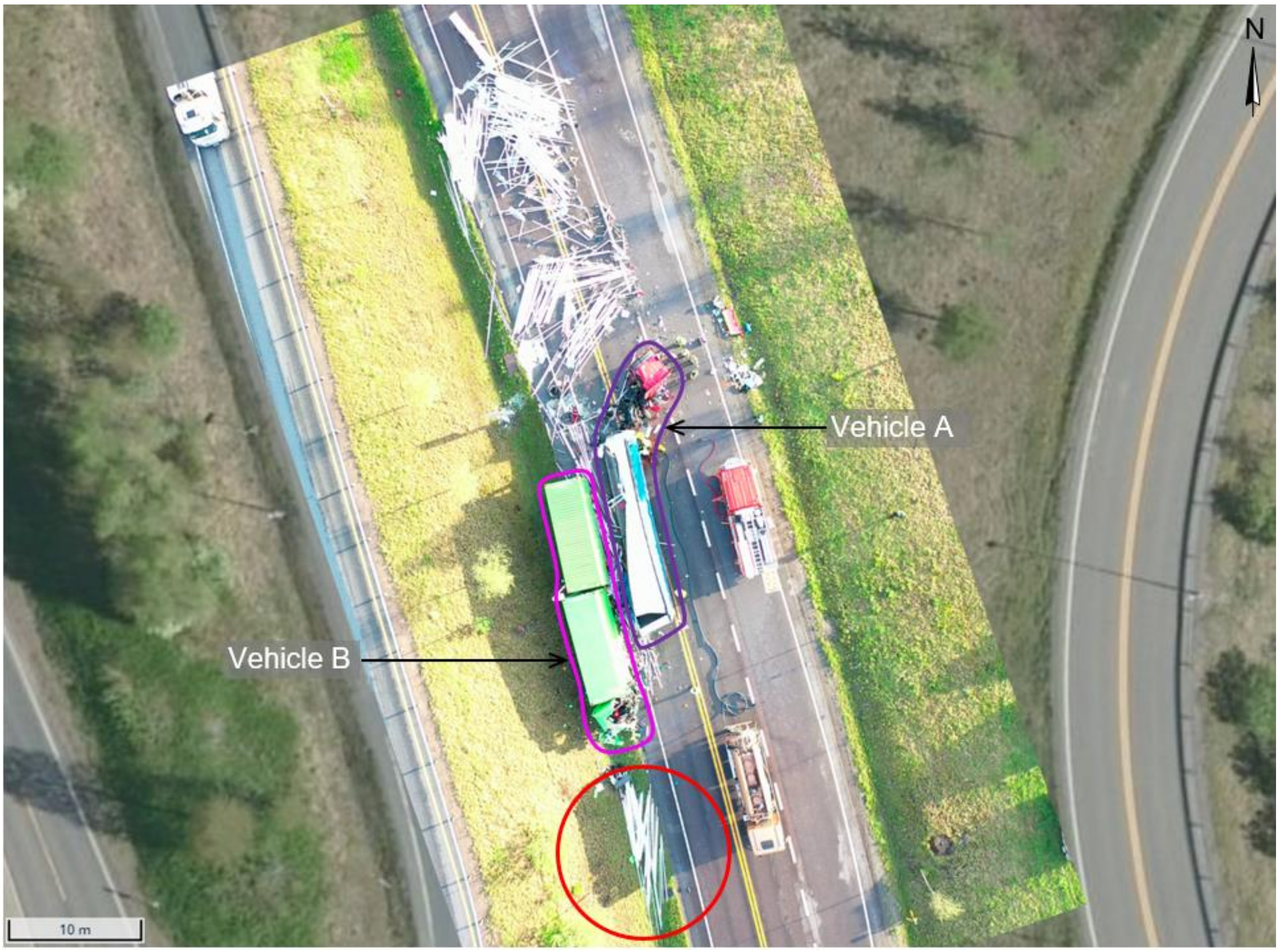

Figure 5: Drone photo giving a general view of the scene, taken just under three hours after the collision. At that point in time, the aluminium sections marked with a red circle had been removed from the driver's side and the front of Vehicle B to facilitate rescue. Photo: © Norwegian Mapping Authority. Drone photo and illustration: NSIA

1.6 Weather and road-surface conditions

The accident occurred under ordinary twilight conditions[3][4], in dry weather with light clouds and an outdoor temperature of approximately 5 °C.[5] The road was free of ice and snow, but humid. Precipitation had most recently been recorded the day before, at 21:10 on 26 May 2021.[6]

1.7 Road users

1.7.1 DRIVER OF VEHICLE A

1.7.1.1 General information

The driver of Vehicle A was 30 years old and held a driving licence covering the categories C1, C, C1E and CE (issued 9 January 2018). The driver was an employee of the Slovenian transport company Dobravc transport d.o.o. and was on a driving assignment for Raufoss Technology AS. He had driven trucks since he gained employment with the company on 3 January 2018, and was estimated to have covered the stretch between Ljubljana and Raufoss more than 30 times. A summary of his final trip up until the time of the collision is given in Table 3.

Table 3: Summary of the driving route from Ljubljana to the point of collision. Source: Dobravc transport d.o.o. and interview with the driver. Table: NSIA

Date	Time	Place
24 May 2021	18:41	Departed Ljubljana
24 May 2021	23:23	Crossed the border from Slovenia to Austria
25 May 2021	06:39	Crossed the border from Austria to Germany
26 May 2021	07:15	Drove onto ferry from Rostock (Germany) to Trelleborg (Sweden), scheduled to leave at 08:00.
26 May 2021	14:14	Drove off the ferry in Trelleborg and crossed the border from Germany to Sweden
27 May 2021	01:06	Crossed the border from Sweden to Norway
27 May 2021	03:15	Time of collision

1.7.1.2 Working hours, sleep and rest

Through collating what the driver himself reported about sleep and activity during the days preceding the accident and data about the driving route obtained from the transport company's fleet management system, it was verified that the regulations relating to driver working time and driving and rest hours[7] were not breached (see table in Appendix A).

The collation shows that the driver had been awake for approximately 13 hours and 15 minutes when the accident occurred, of which approximately 8 hours were spent driving and nearly 4 hours were spent on other work. During the approximately 51 hours before that, from the time the driver

[3] https://www.timeanddate.no/astronomi/sol/@3138321?maaned=5&year=2021
[4] 'Ordinary twilight conditions: The sun is less than six degrees below the horizon. As a rule, enough light to not need artificial light for working outdoors' ('Hva er tussmørke?', 2015).
[5] Recorded at 03:10 at the NPRA's weather station approximately 4 km south of the scene of the accident (Rv. 4 Gjelleråsen).
[6] Norwegian Public Roads Administration (Road weather).
[7] Regulations of 10 June No 543 concerning working time for drivers and others in road transport and Regulations of 2 July 2007 No 877 relating to driving and rest periods for road transport in the EEA. These regulations implement European regulations, which Norway is committed to comply with under the EEA Agreement.

started work on the day of departure (Monday 24 May 2021 at 11:00) until he drove off the ferry in Trelleborg, he slept approximately 19 hours in total, divided between five periods. The driver had been off work on the previous Friday, Saturday and Sunday, and he said that, as far as could remember, he had slept well during the nights preceding the day of departure.

The driver told the NSIA that he did not normally feel pressed for time at work, and that his employer was good in that he did not put pressure on him or his colleagues. For example, they had been ordered to follow the rules on driving and rest periods and to stop if they felt tired or drowsy. When the driver was in Sweden on the day before the accident, he and a colleague were told by their boss that there was no hurry to reach the destination, and that they might want to wait before driving into Norway. The driver chose to drive on nonetheless.

The driver had habitual routines and actions that he would take if he felt tired while driving. They consisted of changing position in his seat, listening to loud music, stopping and leaving the cab, rinsing his face in cold water and taking a few rounds around the vehicle to help his blood circulation. He was intent on not using the automatic cruise control function at night, since manual driving gave him greater control and more to concentrate on.

The driver has been shown the logged speed development between Svinesund and the point of collision, and he has told the NSIA that there was nothing unusual in his style of driving or choice of speed from there to the Hagan tunnel. Despite not having any memory of the final part of the trip before the accident, however, he voiced the opinion that it was very strange and extraordinary for him reach such a high speed inside the Hagan tunnel. In his view, he must either have lost consciousness or fallen asleep. He was not in the habit of cutting corners.

When interviewed by the NSIA, the driver confirmed that the vehicle was sparsely equipped with safety equipment, including that there was no technical driver support system and that, for that reason, it should not have been used for long-distance haulage.

1.7.2 DRIVER OF VEHICLE B

The driver of Vehicle B was 58 years old and held a driving licence covering the categories A, BE, CE and T (issued 26 September 2002). The driver was an employee of the Norwegian transport company Hauer Rauma AS and was on a driving assignment for Bring, Posten Norge AS. According to his employer, the driver had covered the route in question many times and was well-acquainted with the road and the route.

1.8 Medical and health information

According to the conclusion following the toxicological examination of the blood sample taken from the driver of Vehicle A, conducted by the Department of Forensic Medicine at Oslo University Hospital, it is unlikely that the driver was under the influence. When interviewed by the NSIA and questioned by the police after the accident, the driver stated that he had not used any medication, alcohol or drugs on the trip.

According to the conclusion following the autopsy of the deceased driver of Vehicle B, conducted by the Department of Forensic Medicine at Oslo University Hospital, neither ethanol (alcohol), drugs nor narcotics were detected by the toxicological examination of blood and urine.

1.9 Vehicles

1.9.1 GENERAL INFORMATION

Table 4: Vehicle data

	Vehicle A	Vehicle B
Registration, make, specifications:	The tractor unit for Vehicle A was a Slovenian registered Volvo FH13A42T (2015 model). The semi-trailer was of the make Schmitz Cargobull (2019 model).	The truck of Vehicle B was a Norwegian registered MAN TGX26.5406X2-2LL (2014 model). The drawbar trailer was of the make Trailer-bygg (2006 model).

Vehicle B showed traces of braking action in the form of dark patches on the tyres of the truck's rearmost axle and the second-last axle on the drawbar trailer (see Figure 6).

Figure 6: Traces of braking action in the form of dark patches on one of the tyres of the second-last axle on Vehicle B's drawbar trailer. Photo: NPRA.

In the NPRA's accident report (2021), the tractor unit and truck of vehicles A and B, respectively, were both assessed as having been in good technical order before the accident. Both vehicles were equipped with an anti-lock braking system (ABS brakes). The NPRA inspected the brakes visually after the accident, without finding any faults or defects that could have had a bearing on the accident.

1.9.2 DRIVER SUPPORT SYSTEM

The tractor unit of Vehicle A was equipped with a system for automatic cruise control, but its function was limited to increasing the speed. The system was not meant to be able to lower the speed. The tractor unit also has a system for limiting the speed (speed limiter). In the examination after the accident, the NPRA (2021) did not find that this system had been tampered with. The tractor unit was not equipped with a retarder.

The tractor unit of Vehicle A had no technical driver support system that could intervene or warn the driver and prevent the vehicle from leaving its lane (Lane Keeping Support), or warn the driver if he was about to fall asleep (Driver Alert Support). A Lane Departure Warning System (LDWS) has been mandatory in group N2 and N3 (trucks) vehicles and some other vehicle groups since

2012, with effect for new vehicles in the EEA Member States from 1 November 2015.[8] The tractor unit was built in week 41 in 2015 and was therefore not subject to this requirement.

As from 7 July 2024, it will be mandatory for all vehicles in EEA Member States to have a Driver Drowsiness and Attention Warning (DDAW) system.[9]

1.9.3 STOWAGE AND SECURING

Vehicle A carried cylinder-shaped aluminium sections, with diameters of 55 and 79.9 mm and lengths of approximately 5.0 and 5.3 metres, consisting of bundles with packaging. The cargo had a total weight of approximately 23,000 kg, and the gross vehicle weight was 38,200 kg.

Vehicle B carried two empty containers with reported unladen weights of 3,410 kg and 4,000 kg, respectively. Vehicle B had a gross vehicle weight of 22,100 kg.

Vehicle A's semitrailer was built in accordance with the EN 12642 XL standard, with a front wall that was designed to withstand 13,500 daN. Load restraint straps and signs of them having been used to secure the bundles of aluminium section were found at the scene of the accident. The load restraint straps were approved in accordance with EN 12195-2 and marked as capable of restraining five tonnes. The scope of damage after the accident made it impossible to ascertain how the load had been secured, and whether it had been secured in accordance with applicable requirements[10] at the time of the collision.

1.10 Technical registration systems

1.10.1 TACHOGRAPH DATA

The NSIA has examined tachograph data from Vehicle A and compared them with map data in order to determine what route the driver is most likely to have followed from Svinesund to the point of collision. The route was most probably along the E6 road to RV 150 (Ring 3) at Ulven, then onwards to the Sinsen crossroads and onto RV 4 to Gjelleråsen and the point of collision near Slattum. The driver of Vehicle A who survived, could not remember anything about the route taken from Svinesund to the point of collision, but told the NSIA that he had usually taken this route on previous trips to Raufoss.

Data from Vehicle A's tachograph[11] show that large parts of the distance from Svinesund to the point of collision were covered at a speed close to the speed set on the speed limiter (90 km/h), and that some sections were covered at a speed exceeding the speed limit. Vehicle A's highest speed along this stretch of road was logged in the Hagan tunnel, where the tachograph logged a maximum speed of 106 km/h (see Figure 9).

[8] Regulation (EC) No 661/2009 of the European Parliament and of the Council of 13 July 2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor and Commission Regulation (EU) No 351/2012 of 23 April 2012 implementing Regulation (EC) No 661/2009 of the European Parliament and of the Council as regards type-approval requirements for the installation of lane departure warning systems in motor vehicles. Implemented in Norwegian regulations through Regulations of 5 July 2012 No 817 on approval of road vehicles and road vehicle trailers (the Norwegian Road Vehicle Regulations).
[9] Commission Delegated Regulation (EU) 2021/1341 of 23 April 2021 supplementing Regulation (EU) 2019/2144 of the European Parliament and of the Council by laying down detailed rules concerning the specific test procedures and technical requirements for the type-approval of motor vehicles with regard to their driver drowsiness and attention warning systems and amending Annex II to that Regulation.
[10] Regulations of 25 January 1990 No 92 on the use of road vehicles, implementing European regulations that Norway is committed to comply with under the EEA Agreement.
[11] The tachograph has a possible error margin of approximately ± 6 km/h.

Downloaded tachograph data from Vehicle A show that it held an even speed of 78 km/h during the final seconds before the collision, and that the speed dropped from 78 km/h to 19 km/h in the course of one second (see Figure 7). Another four seconds then passed before it came to a complete standstill after the collision.

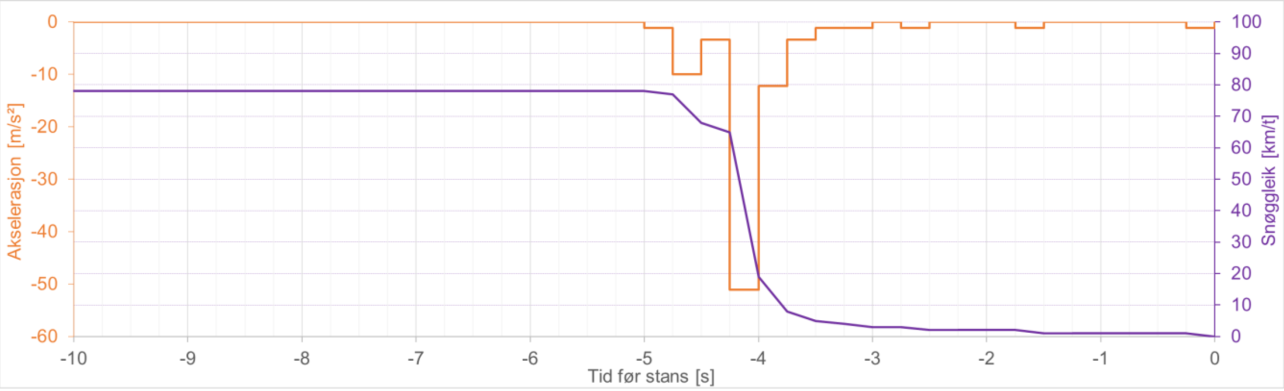

Figure 7: Vehicle A's speed and acceleration during the seconds immediately before and after the collision. The data are presented as retrieved from the tachograph in the tractor unit, with a resolution of four log entries per second. Tachograph data from the tachograph in Vehicle A's tractor unit. Illustration: NSIA

Downloaded tachograph data from Vehicle B show that it held an even speed of approximately 85 km/h during the final seconds before the collision (see Figure 8). The data also show that the speed dropped to 55 km/h in the course of 1.75 seconds, and then to 8 km/h in the course of 0.25 second. One more second passed before the tachograph lost its power supply. The final speed logged before the power failed was 4 km/h.

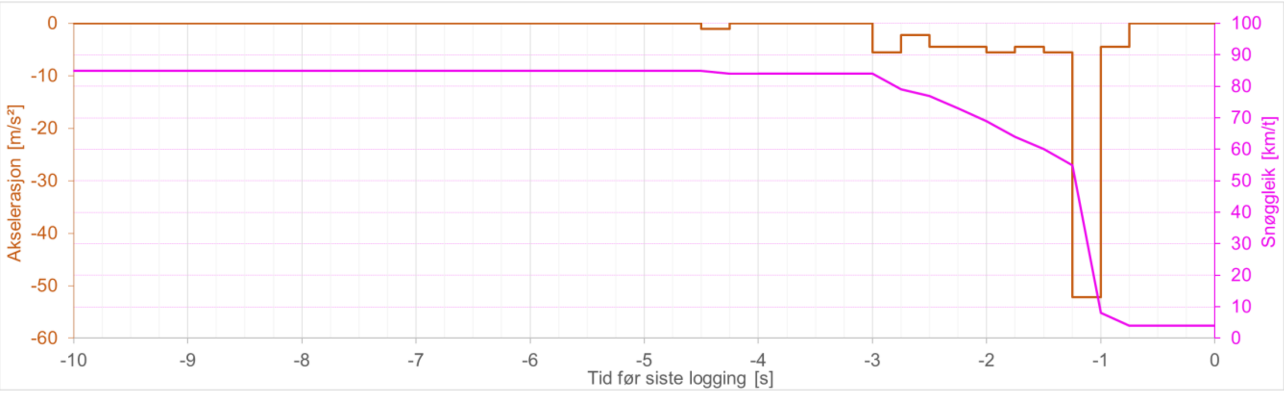

Figure 8: Vehicle B's speed and acceleration during the final seconds before the collision up until the power supply failed. The data are presented as retrieved from the tachograph in the truck, with a resolution of four log entries per second. Tachograph data from the tachograph in Vehicle B's tractor unit. Illustration: NSIA

1.10.2 TELECOMMUNICATIONS DATA

Logged telecommunications data linked to one of the mobile phones belonging to Vehicle A's driver show that he sent and received data packages regularly during the final hour and a half or so before the collision. The NSIA has not looked into the content of these data packages. When questioned by the police, the driver explained that his mobile phone was connected to the loudspeaker system in the cab, and that, while driving, he only touched it to receive incoming calls.

1.10.3 SATELLITE-BASED GLOBAL POSITIONING SYSTEM (GPS)

A GPS unit[12] belonging to Vehicle A was found after the accident. The police's investigation of the unit indicated that it may have been in use up until the time of collision. The driver told the NSIA

[12] *GPS is an acronym for Global Positioning System (satellite-based positioning and navigation system).*

that he was not sure whether he used the GPS or not. He normally preferred to drive without this navigational aid, but nonetheless, he habitually turned on the GPS unit at Svinesund entering the address of his destination at Raufoss. He also told the NSIA that he probably made little use of the GPS while approaching the point of collision, as he knew this part of the road well.

1.11 Road and infrastructure

The RV 4 road is one of the main roads north from Oslo. The road goes through Nittedal, Hadeland and Toten to the bridge across Lake Mjøsa.

On 1 July 2021 the NPRA registered[13] the condition of the paving on the stretch of road where the accident occurred, after the road north of the Hagan tunnel had been given new asphalt paving in 2020 (the road going south to the roundabout at Gjelleråsen was given new asphalt paving in 2013). Measurement data from that work show that the cross slope of the last 500 metres of Vehicle A's lane through the curve leading up to the point of collision was generally in accordance with the standards for operation and maintenance of national roads described in *Håndbok R610 Standard for drift og vedlikhold av riksveger*[14] (see Figure 9).

The horizontal curve radius of the left curve varied between approximately 450 and 600 metres up to the point of collision.[15] The transverse and longitudinal evenness of the road was otherwise largely in accordance with applicable requirements.

The NSIA has calculated the longitudinal slope[16] of Vehicle A's lane from the roundabout at Gjelleråsen to approximately 200 metres past the point of collision. The calculations show that the road had a longitudinal slope of approximately 6% from approximately 150 metres south of the Hagan tunnel at Gjelleråsen to approximately 500 metres into the tunnel. The onward longitudinal slope gradually fell to around 0.5% approximately 900 metres into the tunnel and approximately 1,800 metres south of the point of collision. The longitudinal slope was around 1% over the final 300 metres or so south of the point of collision. Figure 9 also shows the speed of Vehicle A and Vehicle B, respectively, as a function of distance travelled.

The NSIA has driven a truck along the road from the roundabout at Gjelleråsen to the point of collision in order to find out how the truck negotiated the final curve before the point of collision. The investigation showed that it was not possible to negotiate the curve without turning the wheel slightly to the left.

[13] The measurements were recorded at intervals of approx. one metre.
[14] Norwegian Public Roads Administration (2014, pages 30–31).
[15] The current requirement for minimum horizontal curve radius in connection with the design of new national roads with a speed limit of 90 km/h and an annual average daily traffic of between 6,000 and 12,000 is 400 metres (Norwegian Public Roads Administration, 2021, page 34).
[16] The NSIA has based its longitudinal slope calculation on the NPRA's registered elevation data and 20-metre intervals.

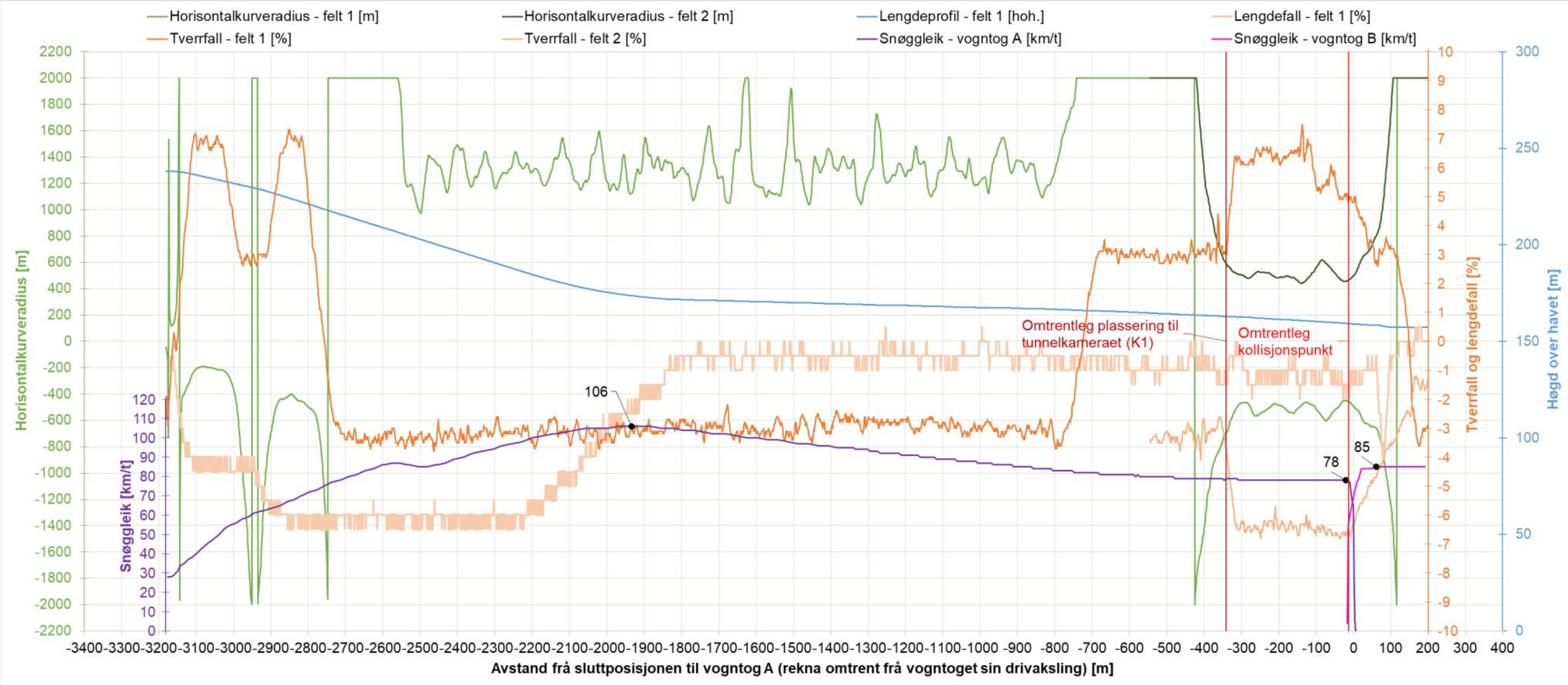

Figure 9: Horizontal curve radius, cross slope, longitudinal slope and longitudinal profile of Vehicle A's lane (Lane 1) and driving direction from approximately 3,200 metres south to approximately 200 metres north of the point of collision (marked with a vertical red line), and horizontal curve radius and cross slope in the southbound lane (Lane 2) from approximately 550 metres south to approximately 200 metres north of the point of collision, collated with the speed development of Vehicle A and Vehicle B, respectively, until they reached their final position. Negative radius values indicate curving to the left and positive cross-slope values indicate sloping to the left, viewed from the driving direction in each lane. Data about the road: NPRA Tachograph data from the tachographs of Vehicle A and Vehicle B, respectively. Illustration: NSIA

1.12 Special investigations

1.12.1 EXAMINATION OF VIDEO RECORDINGS

The Traffic Control Centre (TCC) had three CCTV cameras in operation near the scene of the accident, each recording different parts of the sequence of events during the final 30 seconds or so before the collision. All three cameras pointed southwards. One camera monitored traffic developments inside the Hagan tunnel, while the other two monitored the barriers at the northern side of the tunnel. Video recordings from these cameras were secured after the accident, in which it was possible to observe parts of Vehicle A's passage through the tunnel as well as the actual collision.

The CCTV recording from one of the cameras (K1), located inside the tunnel approximately 200 metres south of the northern tunnel portal, shows that Vehicle A remained in its (northbound) lane until it disappeared from the camera's view (see Figure 10).

Another CCTV camera (K2) located approximately 30 metres north of the tunnel portal and approximately 90 metres south of the point of collision[17], shows that Vehicle A was almost entirely in the southbound lane when it left the tunnel (see Figure 11). This was approximately nine seconds after Vehicle A had disappeared from the view of the camera inside the tunnel.

The recording from the third CCTV camera (K3), located approximately 250 metres north of the point of collision, shows Vehicle B travelling in its own (southbound) lane (see Figure 12).

Figure 10: Screenshot from the K1 recording, showing the position of Vehicle A approximately 1.5 seconds before it disappeared from the camera's view. Source: NPRA

Figure 11: Screenshot from the K2 recording, showing Vehicle A passing through the tunnel portal in the opposite lane. Source: NPRA

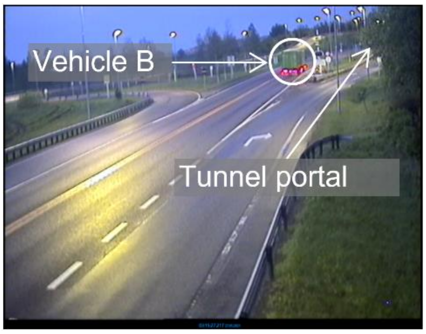

Figure 12: Screenshot from the K3 recording, showing the position of Vehicle B when Vehicle A passed through the tunnel portal. Source: NPRA

The NSIA has examined the three CCTV recordings and recordings from the police reconstruction of the accident. In addition, the NSIA has performed measurements to determine the approximate relative positions of the two vehicles at different times. The measurements were obtained using the Norwegian Mapping Authority's aerial photos and survey tools[18], tachograph data and projective geometry.[19] The investigation and projected measurements showed that vehicles A and B were both approximately 105 metres (± 5 metres) from the point of collision when Vehicle A passed the

[17] *There were no traces to show the exact point of collision. Based on downloaded tachograph data and calculation of distances travelled, the NSIA has identified the point of collision as the point at which there was a sudden drop in speed (see Figure 9).*
[18] https://kystinfo.no/
[19] https://snl.no/projektiv_geometri *(See an explanation of the method used by the NSIA under the heading* 'Constructing a projective scale' *here:* https://math.stackexchange.com/questions/613725/a-formula-for-perspective-measurement

tunnel portal in the opposite lane. That was approximately five seconds before the K3 recording showed the collision taking place.

Figure 13 shows the view from a truck, corresponding to Vehicle A, approximately from where Vehicle A passed through the tunnel portal as shown in Figure 11. Figure 14 shows the view from a passenger car in the approximate position of Vehicle B as shown in Figure 12, when Vehicle A passed through the tunnel portal.

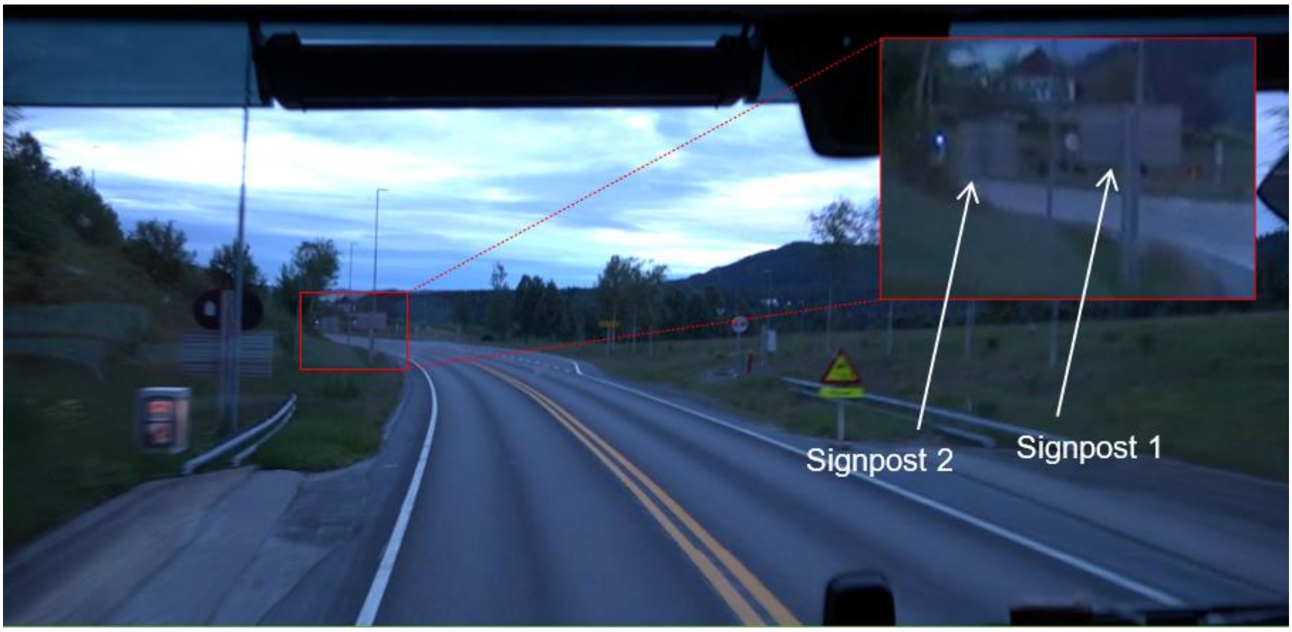

Figure 13: Screenshot from the police reconstruction of the accident, showing the view from a truck leaving the tunnel portal in the opposite lane. Signposts 1 and 2 are marked to enable comparison with Figure 14. Photo: The police. Illustration: NSIA

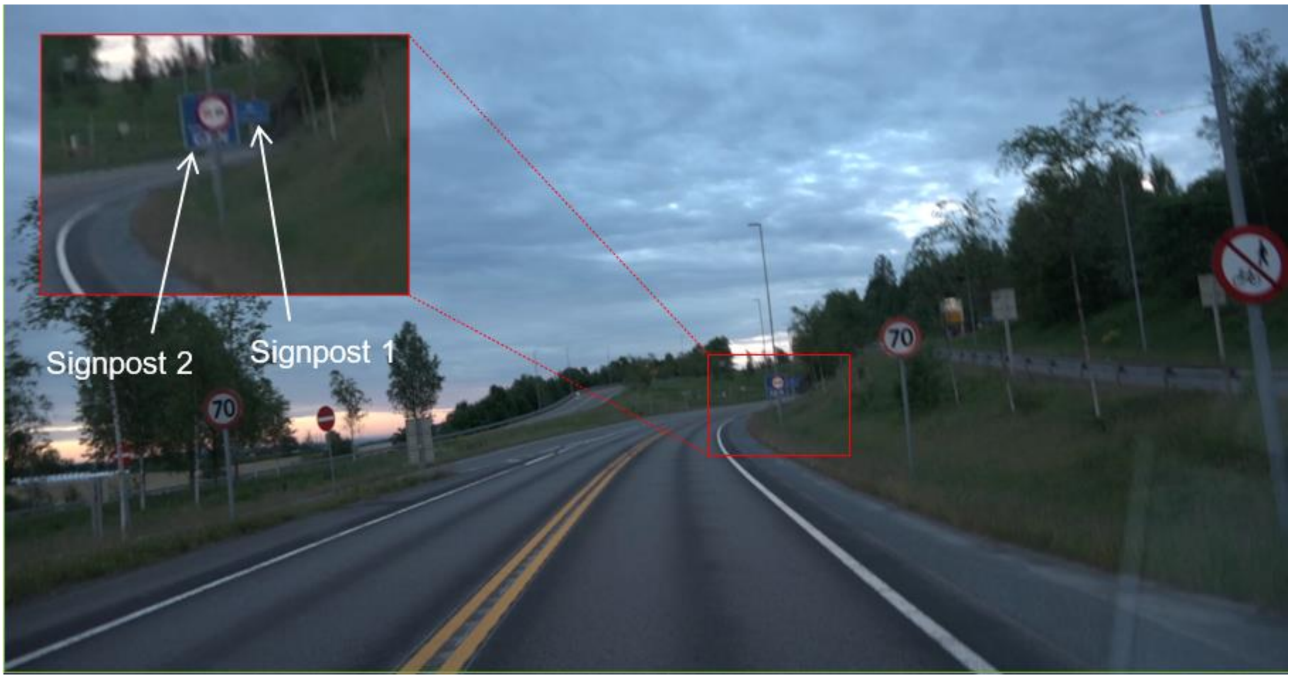

Figure 14: Screenshot from the police reconstruction of the accident, showing the view from a passenger car approaching the Hagan tunnel from the north. Signposts 1 and 2 are marked to enable comparison with Figure 13. Photo: The police. Illustration: NSIA

The investigation work and measurements also showed that it would have been possible for the drivers to spot the headlights of each other's vehicles approximately half a second later, when they were approximately 95 metres (± 5 metres) from the point of collision.

Closer scrutiny of the K2 recording and use of projective geometry showed that, from then on, Vehicle A's turning movement would gradually reduce its distance to the edge line of the opposite lane (see Figure 15). At the first point, the investigation showed that the left wheel set on Vehicle A's trailer was approximately 1.1 metres from the edge line. At the next point, the investigation showed that the distance to the edge line had been reduced to 0.9 metres. The distance and difference in time between the two points were approximately 30 metres and approximately 1.5 seconds, respectively. It was assumed in the investigation that the edge line was approximately 0.17 wide, and that there were approximately 3.4 metres between the edge line and the centreline.[20]

Figure 15: The illustration on the left is based on two screenshots (one on top of the other) recorded by K2 at different times. The purple line illustrates the curve along which Vehicle A travelled in the recording. The white broken lines are used as references to get the right perspective for measurements by the use of projective geometry.
Source: NPRA. Illustration: NSIA
The photo on the right gives an overview of where the accident occurred. The red line marks the approximate point of collision. The blue dots are placed at the same distance from the edge line as shown in the screenshots on the left. The broken purple line shows part of the circumference of a circle with a radius of approximately 500 m.
Photo: © Norwegian Mapping Authority. Illustration: NSIA

The broken purple line in the overview photo in Figure 15 is part of the circumference of a circle with a radius of approximately 500 metres, which intersects these two points. Using a plan drawing of the tunnel in the same scale as the overview photo, the NSIA has traced this line backwards, past the emergency lay-by where the CCTV camera in the tunnel (K1) was located. By drawing the purple line so that it ends on the right-hand side of the road's centreline at K1, the line will pass close to the edge line at the point of collision, indicated by the red line in Figure 15. The purple line will thus cross the centreline approximately 50 metres north of K1.

[20] These widths were based on approximate measurements performed by the NPRA on 18 February 2022, raw data from the NPRA's laser scanning of the road surface 1 July 2021 and use of the ViaPPS Desktop program.

1.12.2 SIMULATION OF VEHICLE A'S SPEED DEVELOPMENT

Based on the longitudinal profile of the northbound lane and tachograph data from Vehicle A, the NSIA has carried out a simplified simulation using the PC-Crash computer program. The purpose was to determine what was required to achieve the speed development of Vehicle A inside the Hagan tunnel and onwards to the point of collision.

A heavy goods vehicle of approximately the same weight and dimensions as Vehicle A was used for the simulation. A 3-km-long road model was constructed, corresponding to the distance to the left of the point of collision in Figure 9, but without the curvature of the real road section. Data from the NPRA's registration of the condition of the paving in the northbound lane were used as a point of departure for the longitudinal profile used in the road model.[21] The simulation resulted the curve shown in Figure 16. For purposes of comparison, the speed as a function of time, as logged by the tachometer in Vehicle A on the real road section, is shown in Figure 17.

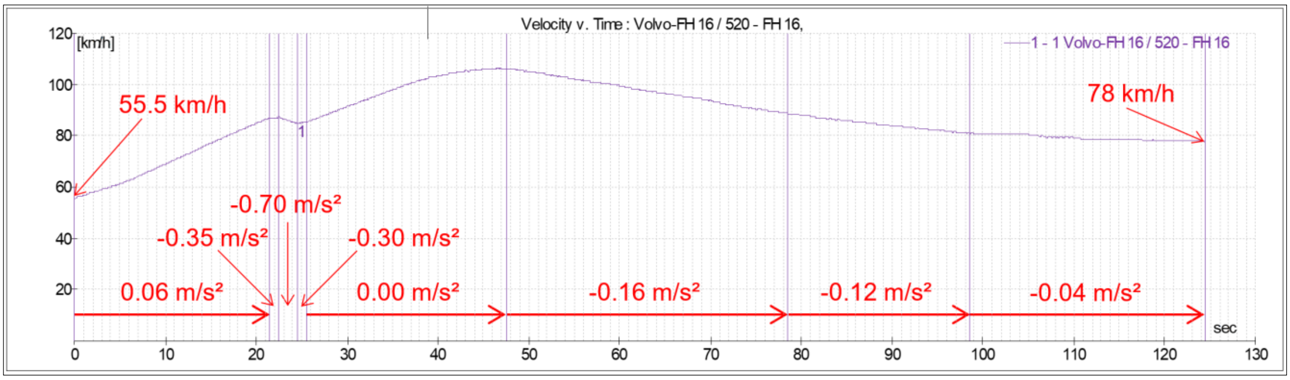

Figure 16: Screenshot from PC-Crash showing the speed development of a heavy goods vehicle model (corresponding to Vehicle A) along a 3-km-long road model (corresponding to the northbound lane on the real road section). Illustration: NSIA

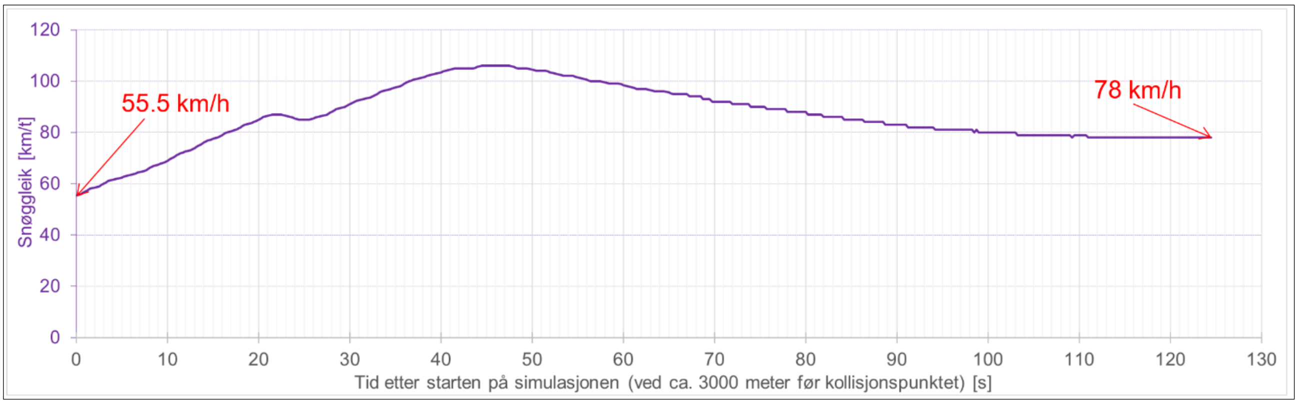

Figure 17: The speed of Vehicle A along the final 3,000 metres or so before the point of collision. The tachograph data are presented as retrieved from the tachograph in the tractor unit, with a resolution of four log entries per second. Tachograph data from the tachograph in Vehicle A's tractor unit. Illustration: NSIA

The speed at the starting point for the simulation was set to the speed at approximately the same point on the real road section (55.5 km/h). A total of eight active speed changes was assumed in order to reach the result in Figure 16. The first speed change (to the far left) consisted of positive acceleration (simulated throttle input), while the remaining seven consisted of negative acceleration (simulated application of the brakes).

[21] *The longitudinal profile of the road model used in the simulation had a resolution of 1 metre and almost coincided with the blue line in Figure 9.*

1.13 Additional information

1.13.1 RESEARCH ABOUT SLEEP AND FATIGUE

How drowsy a person gets, meaning how strong the tendency to fall asleep is, depends on three fundamental body processes (Waage et al., 2007 and Bakotic & Radosevic-Vidacek, 2011):

- time of day, in which the need for sleep is greatest between 03:00 and 06:00 in the morning
- gradually increasing need for sleep with continuous wakefulness
- behaviour and nerve system activation level

The fundamental processes that effect fatigue and the characteristics effects of fatigue are further described in Appendix A.

1.13.2 TRIPARTITE TRANSPORT INDUSTRY PROGRAMME

1.13.2.1 Introduction

The tripartite programme for the transport industry was established by the Norwegian Government in 2014 in order to mobilise employers, employees and government agencies to deal with acknowledged challenges relating to working conditions and working environment in the transport industry, and to get better results than could be achieved by government agencies and the parties separately.

Government agencies contribute to the relevant tripartite industry initiatives with the aid of the Labour Inspection Authority's tools. This has given the Labour Inspection Authority the more clearly defined role of leading this work on behalf of other government agencies.

1.13.2.2 E-guide for ordering transport by road

The tripartite transport industry programme has prepared an e-guide for transport of goods by road: https://www.altinn.no/starte-og-drive/starte/guider-transport/

The guide describes what customers ordering transport assignments must keep in mind, with reference to their accessory liability for the drivers' working hours and the rules on driving time and rest periods.

1.13.3 PREVIOUS ACCIDENTS

The NSIA has previously published reports in connection with accidents in which the driver of the accident-triggering vehicle was asleep or unconscious: (NSIA Report Nos 2014/01, 2015/03, 2020/06). In those cases, the investigations did not lead to any safety recommendations relating to sleep and safety, but it was pointed out in the reports that the accidents could have been prevented by the use of a technical driver support system, and that such systems can improve road safety.

2. Analysis

2. Analysis

2.1 Introduction

The accident occurred in the early hours of the morning when there were few vehicles on the road. There was extensive damage to both vehicle fronts and to the left side of both driver's cabs, and the goods carried by the northbound vehicle broke loose and was scattered across the roadway. The NSIA considers that a collision between two heavy goods vehicles at high speed has the potential to cause extensive harm, and that it was purely by chance that the present accident did not claim two lives.

This chapter starts with an assessment of the sequence of events leading up to the collision in section 2.2. The driver's chosen speed and driving style are discussed in section 2.3. Based on the available information, sleep and fatigue is identified as the most important causal factor behind the accident. Sleep and fatigue are discussed in section 2.4. Technical driver support systems, which can reduce the risk of accidents associated with sleep and fatigue, are discussed in section 2.5. Finally, load securing and its bearing on the scope of the accident is discussed in section 2.6.

2.2 Sequence of events

The collision between the two vehicles occurred after Vehicle A had entered the opposite lane in a left turn with limited visibility. The investigation has shown that the drivers could have spotted the headlights of each other's vehicles approximately five seconds before the collision, at the earliest, and that both vehicles entered the situation at a speed slightly exceeding the local speed limit of 70 km/h. The NSIA does not rule out that it may have been possible for the drivers to become aware of each other at an earlier point in time, as the humid asphalt surface may have reflected the light from the headlights.

At the same time, the NSIA believes that, because visibility was restricted by two relatively big information signs, it may have taken longer before Vehicle B's driver was able to get a full view of Vehicle A approaching in the opposite lane. In the NSIA's view, this can explain why Vehicle B's driver did not apply the brakes before he did. Even if more could have been done in theory, the NSIA believes that the driver of Vehicle B did everything possible to prevent the collision and acted in line with what can be expected of a heavy goods vehicle driver in the given situation. In the two seconds immediately before the collision, shortly after it was possible to detect and understand the situation, he pushed hard on the brake and steered the heavy goods vehicle towards the drainage ditch.

On the other hand, if Vehicle A's driver had been fully conscious, he should have realised that he had veered into the opposite lane as soon as the Vehicle B's headlights became visible. That would have given him five seconds to take action to avoid the collision. Instead, as shown by the investigation, Vehicle A continued its leftward turn up until about two seconds before the collision, and it is probable that the driver only engaged the brakes during the final second before the collision.

The investigation has also shown that Vehicle A probably followed an even curve from the location of the northernmost CCTV camera in the tunnel to the point of collision. The NSIA considers this to be consistent with the driver having fallen asleep and having kept the brake pedal and steering wheel in more or less fixed positions during the seconds leading up to the collision (see 2.4 Sleep and fatigue).

2.3 Choice of speed and driving style of Vehicle A

Tachograph data from Vehicle A show that it exceeded the speed limit for parts of the way from Svinesund to the point of collision. In the NSIA's opinion, however, that alone cannot explain why the vehicle reached a speed of 106 km/h when driving through the Hagan tunnel. The NSIA believes that the speed of Vehicle A through the Hagan tunnel up until the point of collision developed in accordance with the longitudinal slope of the tunnel, the weight of the heavy goods vehicle and an even, passive application of the brakes. The NSIA also believes that the choice of speed cannot alone lead to the conclusion that the driver had a driving style that caused him to cut corners when negotiating the bend leading up to the point of collision.

The driver has stated that he only touches his mobile phone to receive incoming calls, and that he made little use of the GPS unit as he knew the road well. Since the driver remembers nothing from the final part of the drive before the collision, and since the NSIA lacks other technical sources, it can nonetheless not be excluded that Vehicle A entered the opposite lane because the driver was distracted or inattentive, for example as a result of using his phone or receiving instructions from the GPS unit.

2.4 Sleep and fatigue

The accident occurred at 03:15, a time of day that is associated with high melatonin levels in the body, fatigue and increased risk of traffic accidents (see Appendix A). The time of day probably contributed to an unknown degree of fatigue in the driver at the time of the accident.

The comparison between the results of the simulation (shown in Figure 16) and the development of Vehicle A's speed through the Hagan tunnel (shown in Figure 17) indicates that the driver had a passive driving style during the final period leading up to the collision, which can also be an indication of a low level of autonomous activity. A low level of autonomous activity combined with darkness in the driver's cab are consistent with fatigue and sleep.

According to the driver, he had slept normally, that is been awake during the day and slept at night as usual, before he started on the trip from Ljubljana to Norway. In addition, he had slept almost 19 hours, divided between five periods, in the just over 2 1/2 days he had been on the road before the collision. Nonetheless, there are several factors indicating that he may have been drowsy enough to fall asleep, partially or completely, during the final seconds before the collision.

The table in Appendix A shows that the driver did not get a good night's sleep of sufficient length and quality during the nights leading up to 25 and 26 May, respectively. Furthermore, when the accident occurred, he had been awake and mostly working for a total of thirteen hours.

Even if he may have slept well during some periods along the way, he had mostly slept in the daytime. This may have increased the degree of fatigue, as daytime sleep is not as restorative as night-time sleep. The interruption of his established sleep pattern and the transition from several days of night-time sleep to daytime sleep may also have increased the degree of fatigue. Research has shown that, as a rule, people with sleep deficiency need as much as two nights of good sleep before they are fully restored (Åkerstedt et al., 2000, pp. 251–261).

The last time the driver had an opportunity to sleep as normal for almost eight hours, his sleep was interrupted for almost two hours when he drove onto the ferry at Rostock.

The factors

- time of day
- low level of autonomous activity and darkness in the driver's cab

- not enough hours of night-time sleep
- interruption of an established sleep pattern
- inadequate sleep restitution

combine to indicate that the driver was probably affected by an unknown degree of fatigue when the accident occurred. This may have prevented the driver from becoming alerted when he crossed the centreline and rumble strip during the period before the accident.

The NSIA refers to research (Satterfield and Killgore, 2019) into the characteristic effects of fatigue, particularly that individuals pay less attention to the quality of their own work, and that fatigue impairs the capacity for self-assessment and individuals will tend to overestimate their own fitness. This can help to explain why the driver did not become aware of and correct his own speed while passing though the Hagan tunnel.

The present and previous investigations have shown that it is possible to fall asleep behind the wheel even if the requirements for working, driving and rest hours are complied with, and that drowsiness while driving is a safety problem. In submitting this report, the NSIA urges government agencies, transport companies and truck drivers to be aware of this safety problem.

2.5 Technical driver support systems

The tractor unit of the vehicle causing the accident (Vehicle A) had only limited safety devices and no technical driver support system. In that respect, the NSIA agrees with the driver's assessment that the tractor unit should not have been used for long-distance haulage. The NSIA is of the opinion that technical driver support systems, for example Volvo's Lane Keeping Support and Driver Alert Support, can help to prevent accidents caused by fatigue.

As from 7 July 2024, it will be mandatory for all vehicles in EEA Member States to have a Driver Drowsiness and Attention Warning (DDAW) system. Prerequisites for the new regulations to have a positive effect on road safety are that the transport companies as well as those who order transport by road actively choose vehicles equipped with drowsiness and attention warning systems.

In the NSIA's opinion, work should be initiated to increase the use of vehicles with technical driver support systems. The e-guide for ordering transport of goods by road, developed under the tripartite transport industry programme, can be a means whereby customers can specify a requirement for a technical driver support system in their contracts: https://www.altinn.no/starte-og-drive/starte/guider-transport

The NSIA therefore submits a safety recommendation to the tripartite transport industry programme to include a point on technical driver support systems in the e-guide.

2.6 Stowage and securing

The investigation has shown that Vehicle A's cargo, which consisted of bundles of aluminium section, was hurled sideways and forwards through the semi-trailer's left and front walls in the collision, without hitting the truck's cab to any significant degree. The NSIA believes this was because Vehicle A's tractor unit may have been heading to the right when the collision occurred, while the direction of travel of the semi-trailer and cargo were still closer to the longitudinal direction of the road.

The investigation has been unable to ascertain how the load was placed and secured before the collision, but, in the NSIA's opinion, the collision forces must in any case have been greater than what both the approved lashings and the semi-trailer's front and side walls were designed to withstand. The way the aluminium sections were bundled together and wrapped in packaging may have contributed to there being little friction between the sections and to the cargo being scattered across a wide area.

3. Conclusion

3. Conclusion

3.1 Main conclusion

The northbound heavy goods vehicle (Vehicle A) most probably entered the opposite lane because the driver fell asleep, at the same time as he kept the brake pedal and steering wheel in more or less stable positions while he drove through the last part of the Hagan tunnel and onwards to the point of collision. The present and previous investigations have shown that it is possible to fall asleep behind the wheel even if the requirements for working, driving and rest hours are complied with, and that drowsiness while driving is a safety problem. The NSIA is therefore of the opinion that customers ordering transport of goods by road should actively seek out vehicles that are equipped with a DDAW system.

3.2 Results of the investigation

A. The earliest point at which it was possible for the drivers to detect the lights from each other's vehicles was approximately five seconds before the collision.

B. The driver of Vehicle B did just about everything possible to prevent the collision and acted in line with what can be expected of a heavy goods vehicle driver in the given situation.

C. Vehicle A was moving leftwards until about two seconds before the collision, and it is probable that the driver only engaged the brakes during the final second before the collision. The vehicle may have followed an even curve from the location of the northernmost CCTV camera in the tunnel to the point of collision.

D. The speed of Vehicle A through the Hagan tunnel up until the point of collision developed in accordance with the longitudinal slope of the tunnel, the weight of the heavy goods vehicle and an even, passive application of the brakes.

E. A combination of the factors time of day, low level of autonomous activity and darkness in the driver's cab, not enough hours of sleep at night, interruption of an established sleeping pattern and inadequate sleep restitution, indicates that the driver was probably affected by an unknown degree of fatigue when the accident occurred.

F. Drowsiness may have prevented the driver from becoming alerted when he crossed the centreline and rumble strip during the period before the accident.

G. Vehicle A's tractor unit had only limited safety devices and no technical driver support system.

H. As from 7 July 2024, it will be mandatory for all vehicles in EEA Member States to have a driver drowsiness and attention warning (DDAW) system.

I. The collision forces must have been greater than what both the approved lashings and the semi-trailer's front and side walls were designed to withstand.

4. Safety recommendations

4. Safety recommendations

The Norwegian Safety Investigation Authority submits the following safety recommendations[22] for the purpose of improving road safety:

Safety recommendation Road No 2022/12T

The investigation of the head-on collision on the RV 4 road between two heavy goods vehicles north of the Hagan tunnel in Nittedal on 27 May 2021 shows that sleep and fatigue may have contributed to one of the vehicles crossing into the opposite lane. The vehicle had no technical driver support system that could have warned the driver of entering the opposite lane or of safety threats or inattentiveness. As from 7 July 2024, it will be mandatory for all vehicles in EEA Member States to have a Driver Drowsiness and Attention Warning (DDAW) system. The Norwegian Safety Investigation Authority is of the opinion that work should be initiated to increase the use of driver support systems, and it recognises that the tripartite transport industry programme has tools whereby customers who order transport of goods by road can specify a requirement for a technical driver support system in their contracts.

The Norwegian Safety Investigation Authority recommends that the tripartite transport industry programme include a point on technical driver support system in the e-guide for ordering transport of goods by road.

Norwegian Safety Investigation Authority
Lillestrøm, 23 May 2022

[22] The investigation report is submitted to the Ministry of Transport, which will take the necessary steps to ensure that due consideration is given to the safety recommendations, cf. Section 14 of the Regulations of 30 June 2005 No 793 on Public Investigation and Notification of Traffic Accidents etc. Section 14.

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Appendices

Appendix A Facts about sleep and fatigue

The driver's sleep and activity pattern

Collated information about the driver's sleep and activity pattern during the approximately 64 hours that passed before the accident occurred. The figures in this table correspond roughly with data downloaded from Vehicle A's tachograph. Source: Dobravc transport d.o.o. and interview with the driver. Table: NSIA

Date	Time	Activity	Driving time	Rest period	Sleep period
24 May 2021	–11:00	Sleep in own bed			Uncertain
	11:00–12:00	Driving	01:00		
	12:00–13:00	Rest period without sleep		01:00	
	13:00–16:00	Driving	03:00		
	16:00–17:00	Rest period without sleep		01:00	
	17:00–18:50	Driving	01:50		
	18:50–20:01	Rest period without sleep		01:11	
	20:01–21:31	Driving	01:30		
	21:31–22:22	Rest period without sleep		00:51	
	22:22–22:34	Driving	00:12		
	22:34–22:59	Rest period without sleep		00:25	
	22:59–23:04	Driving	00:05		
	23:04–23:13	Rest period without sleep		00:09	
	23:13–23:18	Driving	00:05		
	23:18–23:25	Rest period without sleep		00:07	
Total past 24 hours			*07:42*	*04:43*	-
25 May 2021	23:25–01:44	Driving	02:19		
	01:44–04:11	Rest period with some sleep in the cab			02:27
	04:11–05:33	Driving	01:22		
	05:33–06:38	Rest period without sleep		01:05	
	06:38–08:37	Driving	01:59		
	08:37–11:00	Rest period with sleep in the cab			02:23
	11:00–13:00	Rest period without sleep		02:00	
	13:00–18:13	Rest period with sleep in the cab			05:13
	18:13–19:59	Driving	01:46		
	19:59–20:19	Rest period without sleep		00:20	
	20:19–22:56	Driving	02:37		
	22:56–23:30	Rest period without sleep		00:34	
Total past 24 hours			*10:03*	*03:59*	*10:03*

Table contiunes on the next page.

Date	Time	Activity	Driving time	Rest period	Sleep period
26 May 2021	23:30–03:09	Driving	03:39		
	03:09–03:23	Rest period without sleep		00:14	
	03:23–03:26	Driving	00:03		
	03:26–07:15	Rest period with sleep in the cab			03:51
	07:15–07:45	Rest period without sleep (standing time by the ferry)		00:30	
	07:45–07:52	Driving	00:07		
	07:52–09:00	Rest period without sleep (eating on board the ferry)		01:08	
	09:00–14:00	Rest period with sleep in ferry cabin			05:00
	14:00–14:12	Rest period without sleep		00:12	
	14:12–15:40	Driving	01:28		
	15:40–19:28	Other work			
	19:28–23:20	Driving	03:52		
	23:20–00:09	Rest period without sleep		00:49	
Total in past 24 hours			*09:09*	*02:53*	*08:51*
27 May 2021	00:09–01:07	Driving	00:58		
	01:07–01:34	Rest period without sleep (standing time at the border)		00:27	
	01:34–03:15	Driving	01:41		
Total past 24 hrs			*02:39*	*00:27*	
Aggregate total	**64:15**		**29:33**	**12:02**	**18:54**

Processes that effect fatigue

INTRODUCTION

How drowsy a person gets, meaning how strong the tendency to fall asleep is, depends on three fundamental body processes (Waage et al., 2007 and Bakotic & Radosevic-Vidacek, 2011):

- time of day
- gradually increasing need for sleep with continuous wakefulness
- behaviour and nerve system activation level

TIME OF DAY

Some processes in the body follow close to a 24-hour cycle, such as body temperature and the production of hormones (e.g. melatonin). Light is the most important timer for these fluctuations. The photo-neuroendocrine system transforms light into circadian signals in the brain and affects the melatonin level, often referred to as 'the biological clock'. Light reduces melatonin levels and the need for sleep, while darkness increases melatonin production and the need for sleep (Stehle et al., 2011).

For most people, the need for sleep increases around 22:00 and reaches a peak between 03:00 and 06:00 in the morning. In the daytime, the need for sleep increases slightly sometime in the early afternoon, and then drops again until the next night cycle begins.

GRADUALLY INCREASING NEED FOR SLEEP WITH CONTINUOUS WAKEFULNESS

The body regulates sleep by means of a balancing mechanism that ensures a certain ratio between how long we are awake and how long we sleep. When continuously awake, the need for sleep builds up gradually, while sleep reduces the need. How long it takes to recover after running a sleep backlog varies. Sleep during the day is generally of poorer quality than regular sleep at night, and is therefore not equally suited for restitution from sleep deprivation. A study by Åkerstedt et al. (2000) showed that, when running a sleep backlog, one day's rest (including sleep through the night) is seldom enough. Two days is usually sufficient to feel fit and rested, while three or four days may be required after periods when the circadian rhythm has been severely disrupted.

It is documented in a number of studies that operators who are affected by sleep deprivation clearly have a higher risk of accidents than others. For example, a study among road users showed that less than six hours of sleep before starting work entailed a fourfold increase in the accident risk, while less than four hours of sleep multiplied the risk by 19. Less than 12 hours of night-time sleep in the course of the last two days before starting work increases the probability of a fatigue-related accident (Philips & Sagberg, 2010).

BEHAVIOUR AND NERVE SYSTEM ACTIVATION LEVEL

In general, it can be said that the higher the level of activation of the autonomous nerve system, the less drowsy a person feels. The activation level is different, for example, when you lie down (lowest), sit and stand up (highest). Intense light, noise and physical activity increase the activation level. Mobilisation to deal with an experienced threat or challenge also increases the activation level and is often referred to as a stress response. Monotonous and boring tasks and surroundings lower the activation level (Bakotic & Radosevic-Vidacek, 2011). When the body prepares for sleep, the activation level drops.

M'bailara et al. (2013) studied the relationship between activation and the degree to which drivers contributed to the occurrence of accidents. The study indicated that an extraordinarily high or low level of activity is a contributory cause in many accidents.

Characteristic effects of fatigue

Fatigue, i.e. the combined effect of wakefulness and the time of day, has three characteristic effects (Satterfield and Killgore, 2019):

1. Sleepy individuals are unstable and unpredictable. It is to some degree possible to compensate for the lack of sleep, but often for only part of the work at hand. Satterfield and Killgore (2019) describe this as follow: "*Together, these data illustrate that performance instability is a hallmark of sleep loss. It is this unstable and unpredictable nature that makes fatigue so dangerous, especially in safety-critical operations."* Doran et al. (2001) made similar findings: "*Cognitive impairment due to sleep loss does not constitute a gradual performance decline or a complete failure to perform, but rather takes the form of performance instability."*

2. Sleepy individuals pay less attention to changes in their surroundings and less attention to the quality of their own work.

3. Wakefulness over time impairs physical and mental resources.

It seems clear from existing research that the executive function in particular becomes unpredictable and unstable with fatigue. These functions are located in the frontal lobe, an area of the brain that, among other things, helps us to handle multiple thoughts and ideas simultaneously, think before we act, handle unexpected situations and stay concentrated.

In addition, fatigue has the following effects:

- Fatigue impairs the capacity for self-assessment, and individuals will tend to overestimate their own fitness (Satterfield and Killgore, 2019).
- Individuals will tend to pay attention to what they assume to be the most important factors in a situation, and thus apply a top-down strategy. They will lack flexibility and will not take much note of new factors, and they will have a high threshold for doing anything other than planned tasks (Whitney et al., 2018).
- Individuals affected by fatigue are able to maintain quality in the performance of some tasks, but they have to put more effort into the work (Gould et al., 2009). This reduces their ability to perform tasks other than their primary tasks, i.e. secondary tasks. They take less note of nonconformities in their own performance and will, to a greater extent, deviate from procedures without being aware of it.